Damage Tolerance For Rotorcraft High Cycle Applications

National Rotorcraft Technology Center
December 7-9, 2004

Outline

- Motivation
- Challenges & Objectives
- Threshold Research
- Application to Rotorcraft
- Summary
- Challenges Ahead

Motivation

United States Air Force Damage Tolerance Initiative

- Aircraft structural failures typically occurred from fatigue cracks
- Develop a life-cycle management approach based on crack growth
- Inspect and repair instead of time-based replacement

- USAF improves fleet safety
- USAF improves operational readiness
- USAF saves millions of dollars in replacement costs and downtime

Why not rotorcraft?

Challenges & Objectives

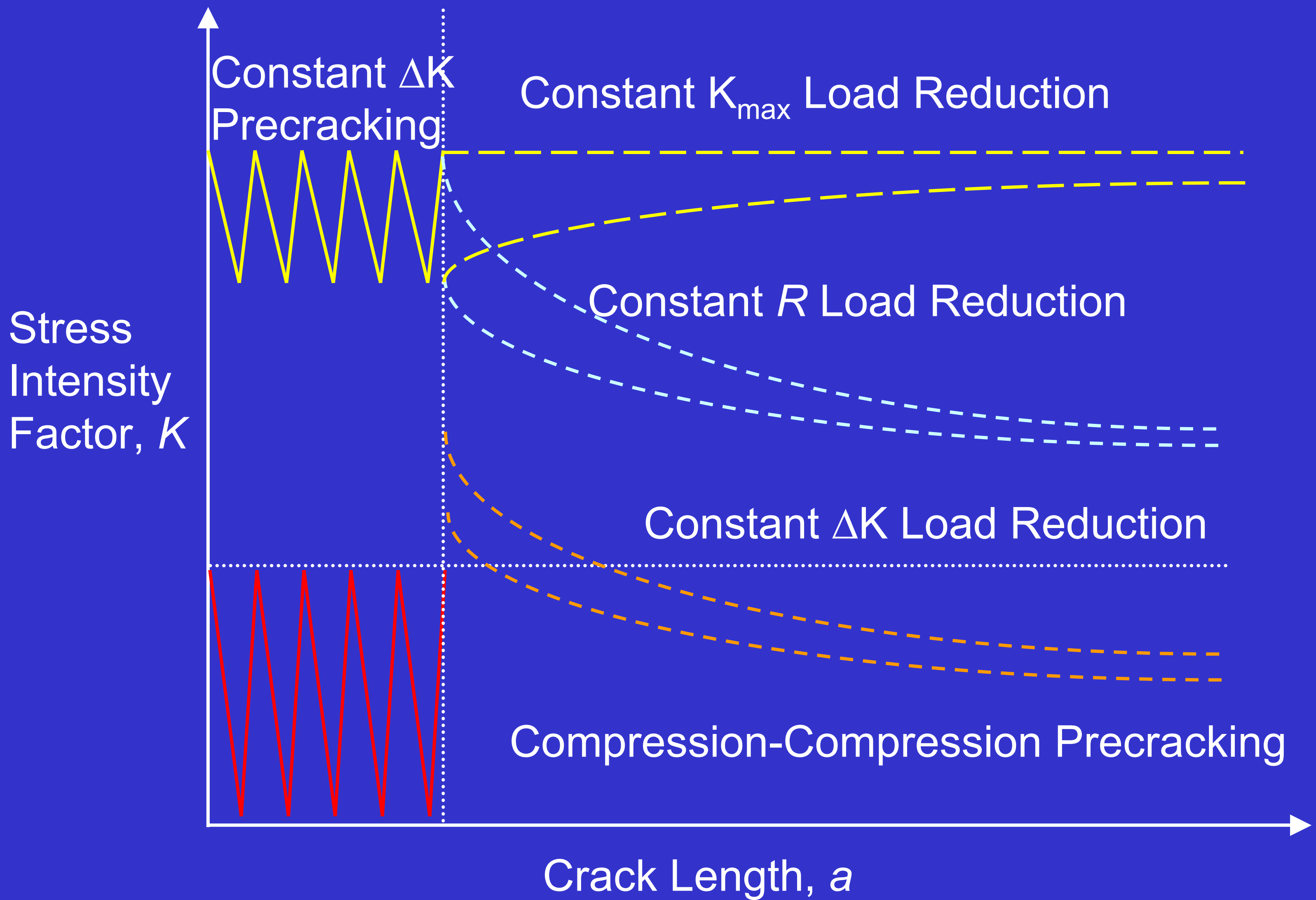
- Rotorcraft OEM's and operators must replace expensive structure repeatedly
- DT offers improved safety at lower cost (USAF)

Challenges

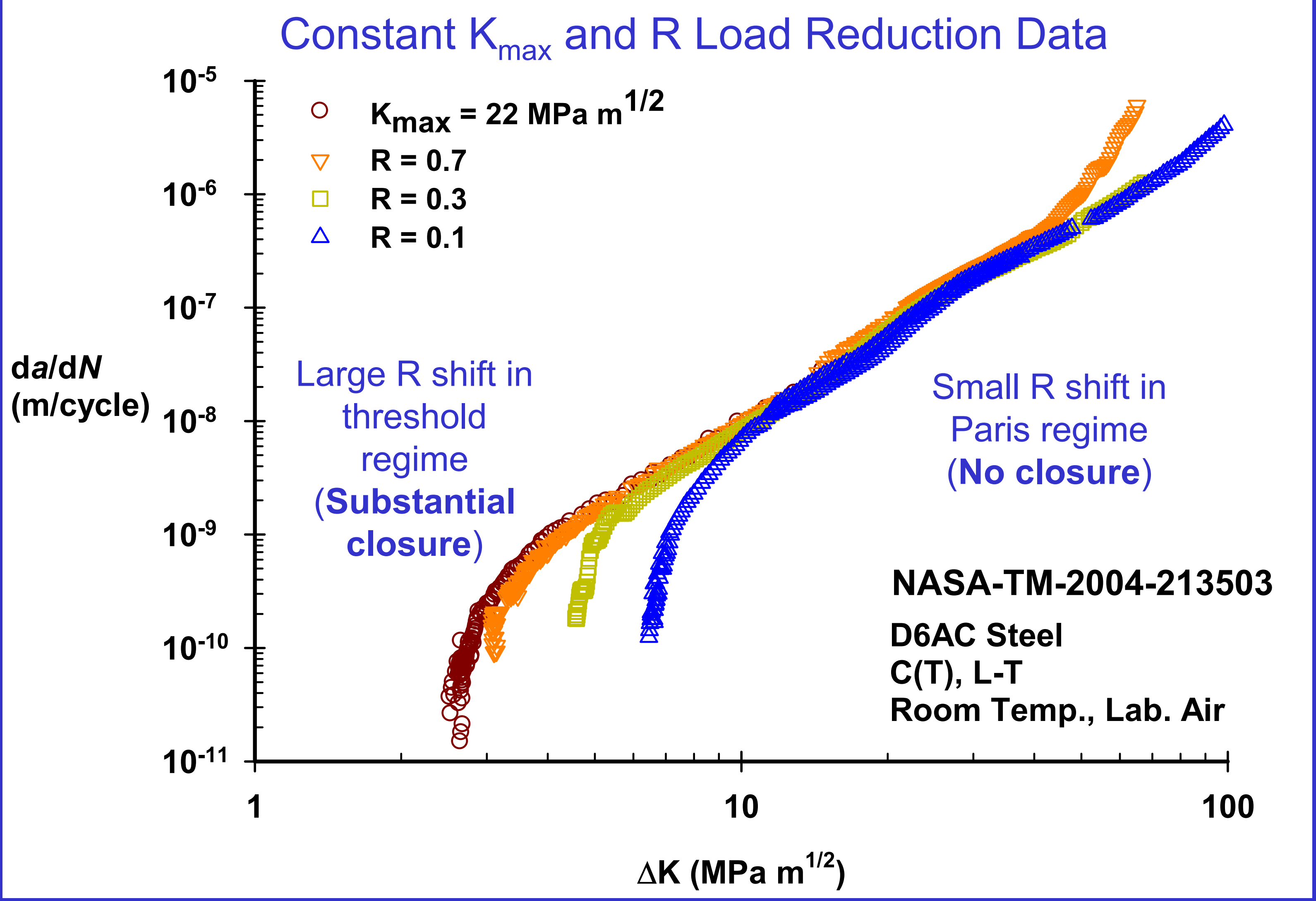
- Rotorcraft structure experience more extreme operating environments than most fixed-wing aircraft
- Significant structural failures typically occur from high-cycle fatigue

- **The objectives of this research are**
  - **Investigate the fatigue crack growth threshold test methods**
  - **Evaluate the applicability of using threshold data for rotorcraft design**

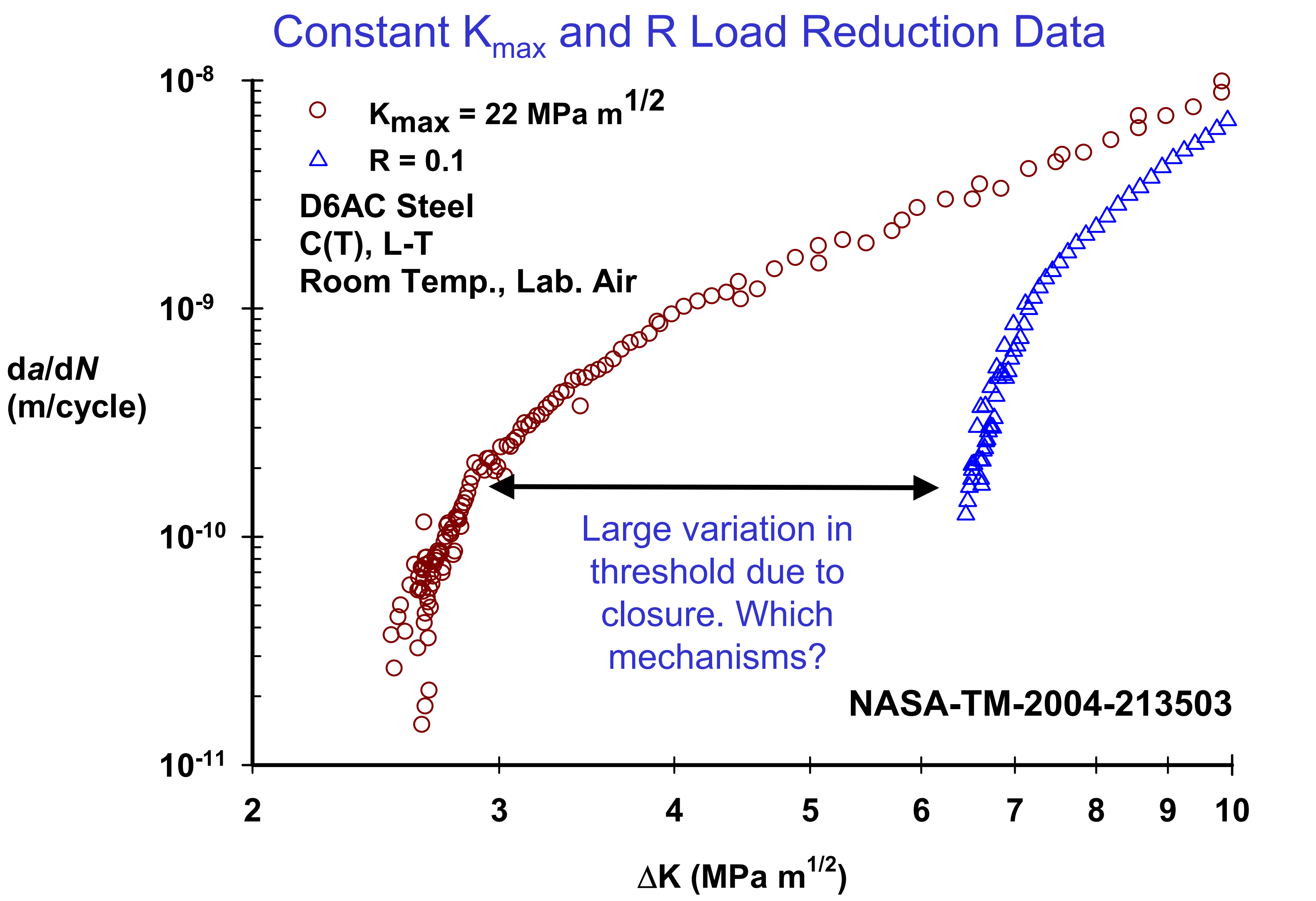
Experimental Threshold Methods



D6AC Steel Crack Growth Rate Data

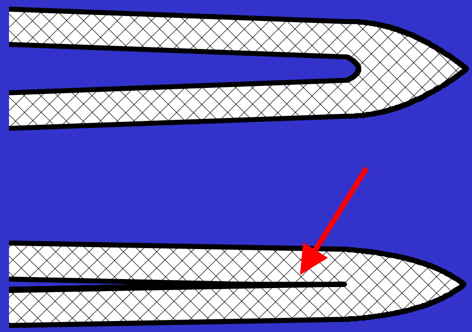


D6AC Steel Crack Growth Rate Data

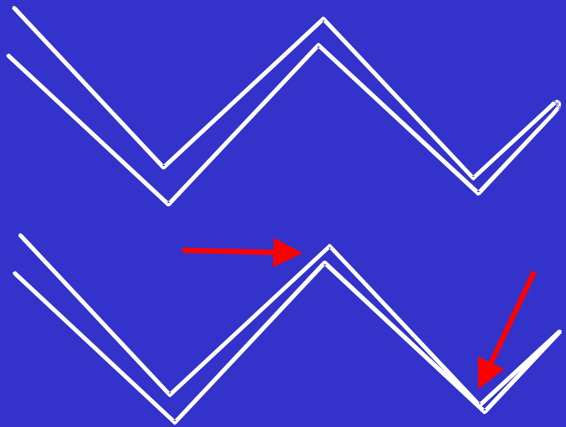


Description of Crack Closure Mechanisms

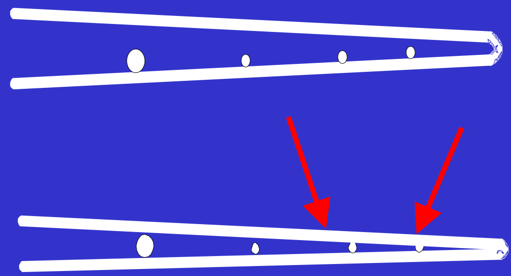
- **Plasticity-induced crack closure**
  - Crack length
  - Cycle count



- **Roughness-induced crack closure**
  - Crack length
  - Material properties

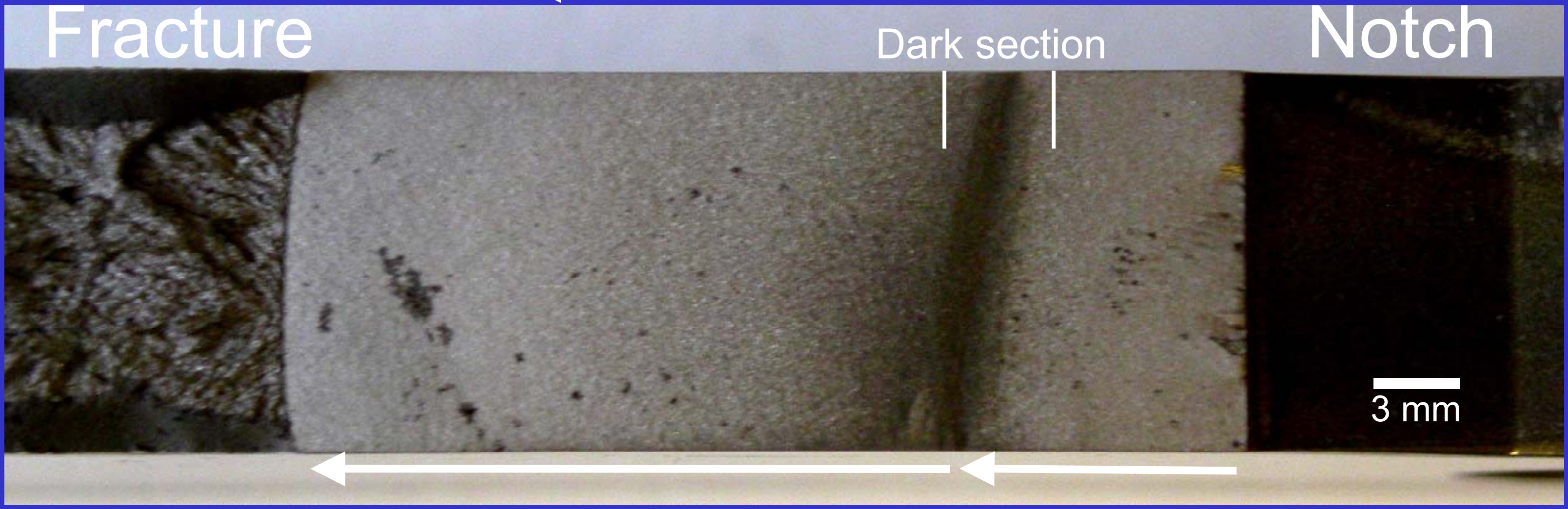


- **Environment-induced crack closure**
  - Crack length
  - Exposure time
  - Material properties



Evaluation Of Environmental-induced Crack Closure At R = 0.1 in D6AC Steel, C(T) Specimen

Direction of crack growth



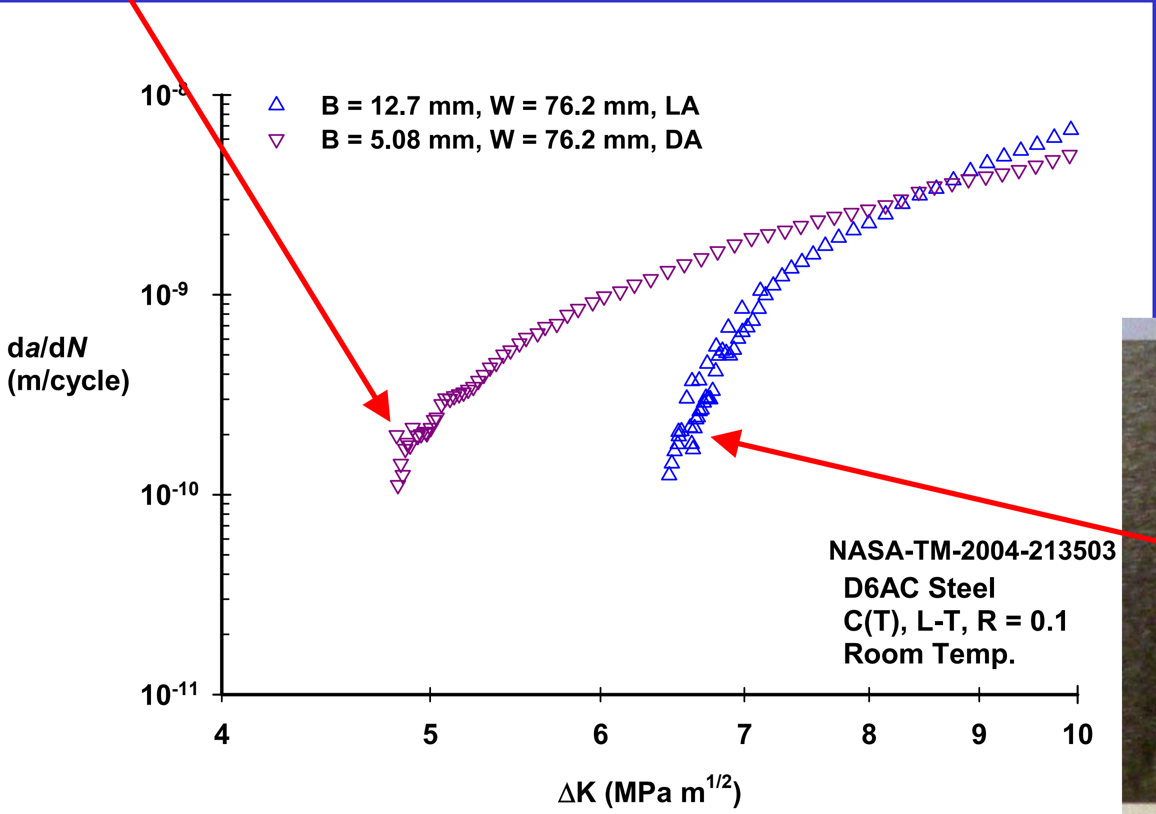
ΔK increasing ΔK decreasing

- **Interpretation**
  - **Threshold region appears darker in ΔK decreasing test**
  - **As ΔK approaches 10 MPa $m^{1/2}$ in ΔK increasing test, fracture surface lightens and crack growth rate is equivalent to high-R "closure free" data**
  - **Closure most likely roughness or environment**

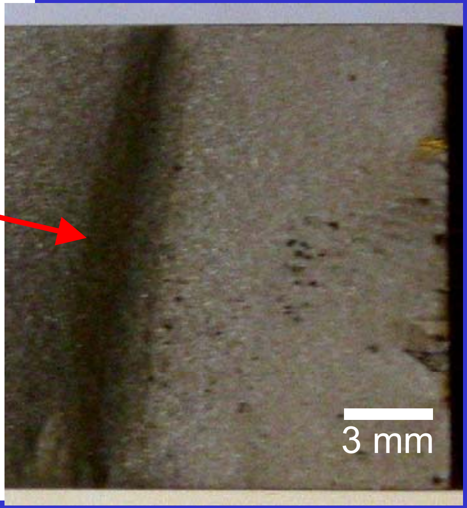
Evaluation Of Environmental-induced Crack Closure

Relative Humidity
< 3%

Direction of crack growth for both photos

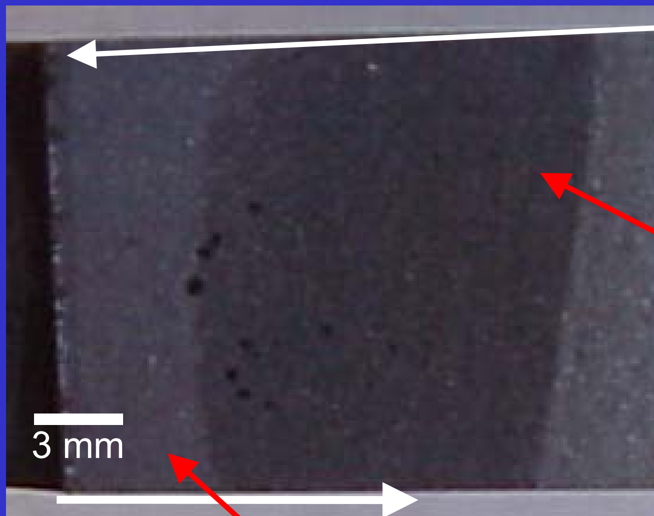


Relative Humidity
> 30%



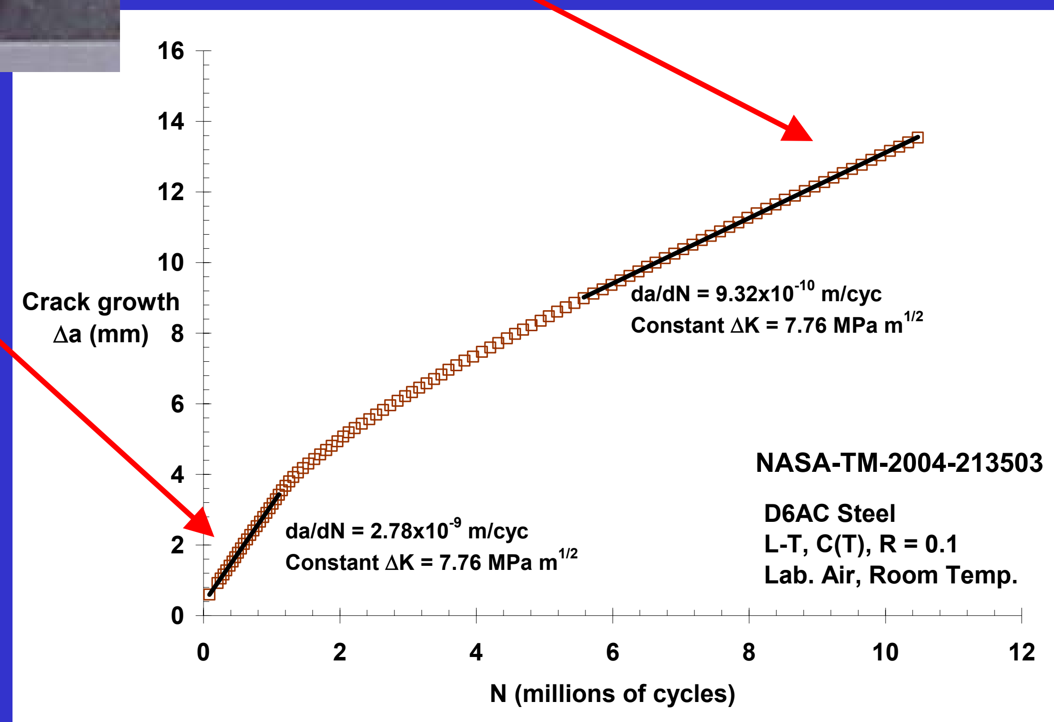
Verification of Environment-induced Crack Closure using Constant ΔK data for 7.7 MPa $m^{1/2}$ in D6AC Steel

Compression precracking



Direction of crack growth

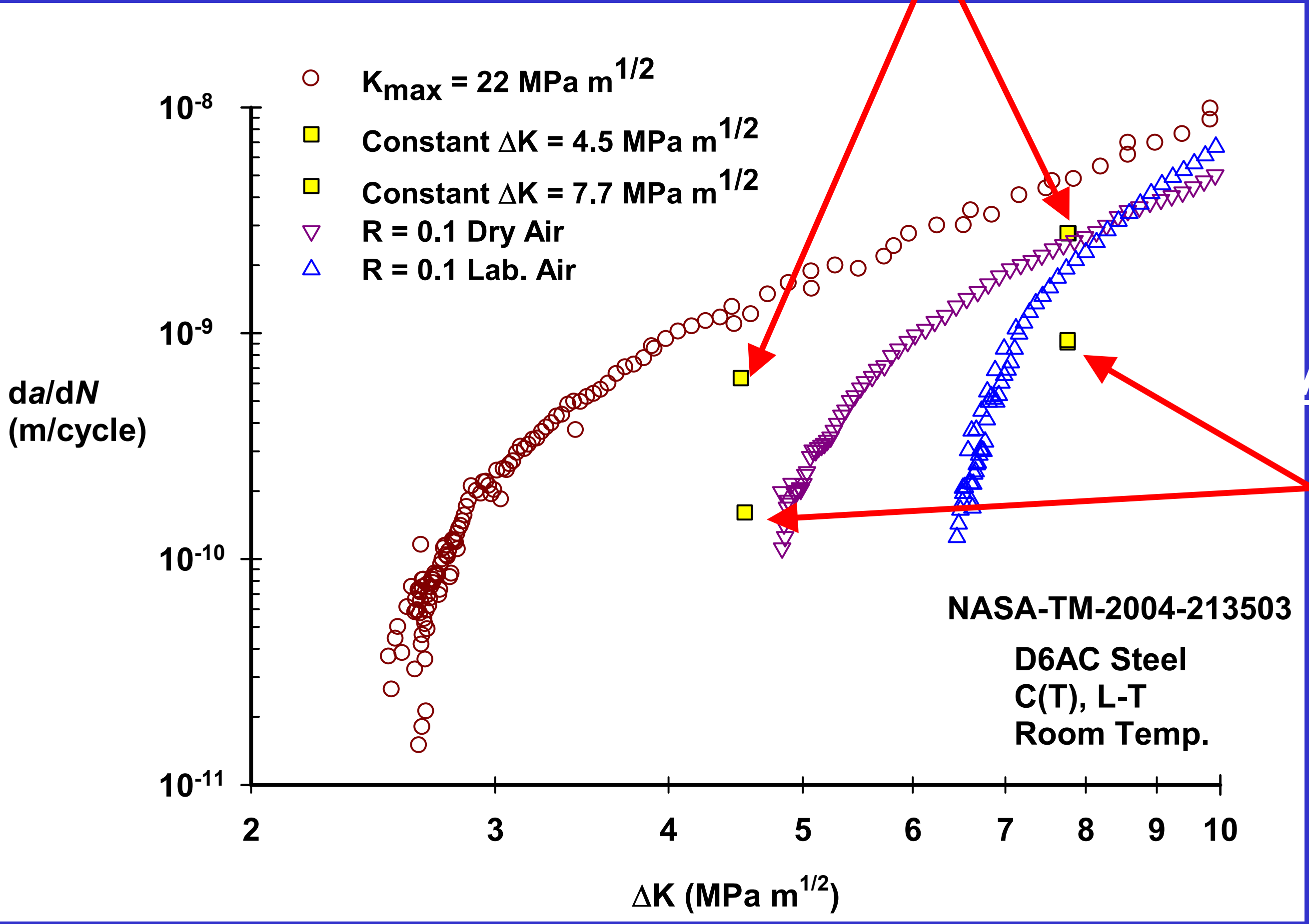
- Slower crack growth rate for same ΔK has a darker fracture surface after 3 days have passed



Comparison of Constant ΔK to Load Reduction Data

Assumption:

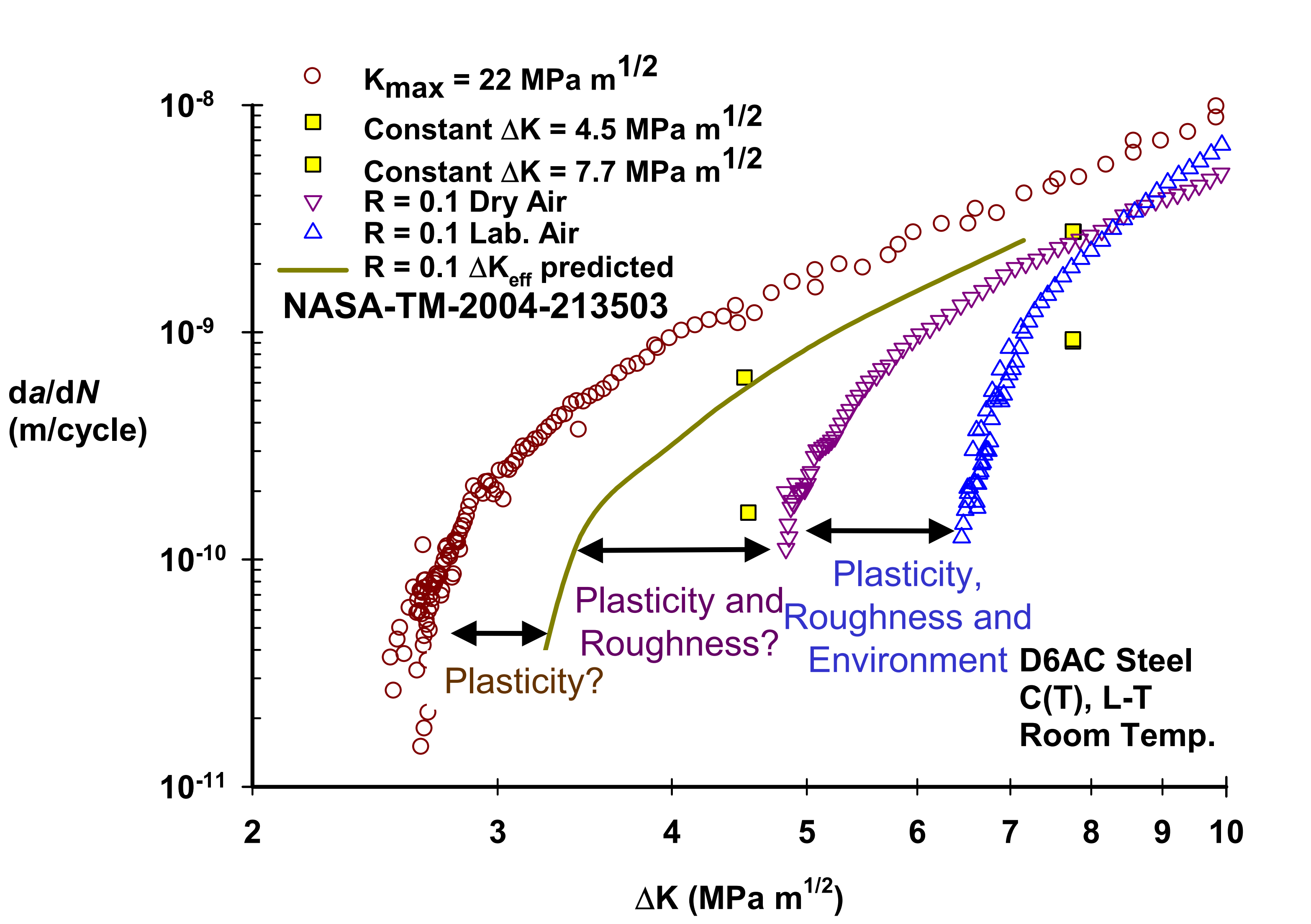
Steady-state plasticity- and roughness-induced crack closure



Assumption:

Steady-state environment-induced crack closure

Crack Closure Development in D6AC Steel

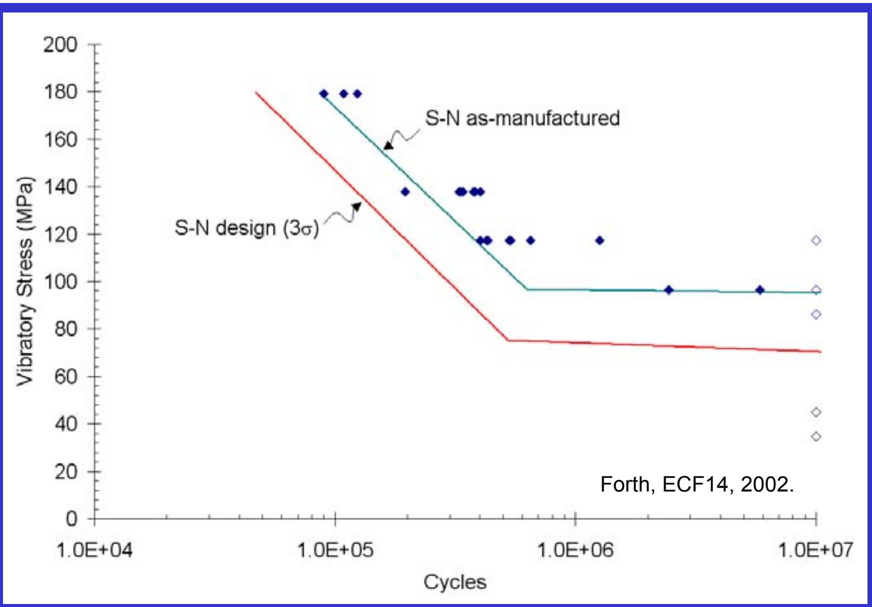


Plasticity model used is FASTRAN effective stress intensity

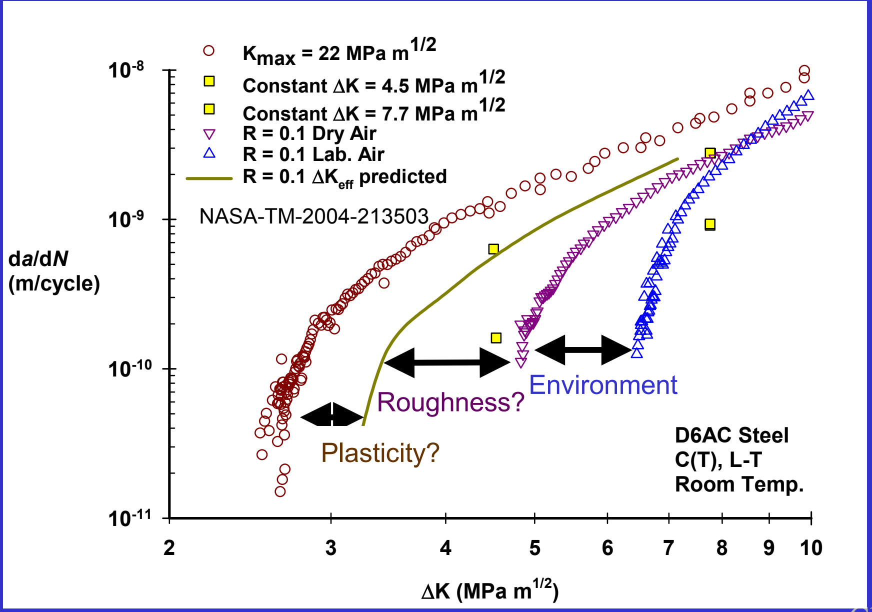
Losing Sight of the Forest

Challenges to Implementing Damage Tolerance in Rotorcraft

- Stress-based life cycle is defined by a material endurance limit
- Well-defined laboratory test method



- Damage tolerance-based life cycle is defined by a material endurance limit, e.g. threshold
- Poorly defined laboratory test method



Summary of Threshold Observations in D6AC Steel C(T) Specimens

Closure Mechanism	Threshold Stress Intensity (MPa $m^{1/2}$)
Closure-free	2.52
Plasticity	3.19
Roughness	4.82
Environment	6.45

$\left.\begin{matrix}3.19\\4.82\\6.45\end{matrix}\right\}$ R = 0.1

- Results from threshold test methods are highly dependent on crack closure mechanisms
- Design and life prediction of high cycle fatigue structure is reliant on a full understanding of the threshold test methods and laboratory environment

Challenges Ahead

- Identify what thresholds are important for rotorcraft damage tolerance.
- Is designing to the fatigue crack growth threshold any different than the endurance limit?
- When does inspection for cracks become affordable or prudent?
- Does DT for rotorcraft improve safety?
- How does one design for stable, inspectable crack growth?